AMMONIA BOILER SYSTEM FLOWRATE CAPABILITY

STATEMENT OF PROBLEM

Ammonia flow rates required for entry cooling increase as a function of storage tank temperatures and can conceivably exceed system capabilities. Excessive requirements as a result of extreme temperatures could require modifications to mission plans to either reduce tank temperatures or cooling requirements. An analysis of worst case conditions has been performed, and indicates that adequate flowrates are available, and consequently no mission impact is anticipated.

ANALYSIS

The maximum flow rate required under extreme conditions would be approximately 300 lb/hr. It was determined, based on hardware specifications, that the parallel NH_3 flow control valves can flow up to 177 lb/hr (354 lb/hr total) if the NH_3 supply remains above 45 psia. Assuming these valves to be the limiting factor in the system, the flow rate capability is dependent upon maintaining adequate pressure in the storage tanks which supply these valves. There is no provision for active pressurization of the storage tanks during a mission. Therefore, tank pressure during NH_3 Boiler operation will be a function of initial conditions, heat transfer across the tank walls, and the thermodynamic properties of the NH_3 in the tank. The ALT configuration, with six uninsulated tanks and no helium prepressurization of the tanks was considered to be the most severe case.

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According to available information, NH_3 temperatures should have an initial value of 95°F with a corresponding saturation pressure of 196 psia. In order to determine worst case conditions for NH_3 delivery, an ambient air temperature and pressure of 0°F and 5 psia (ALT flight conditions) was assumed.

The heat transfer coefficient (UA) of the 6 storage tanks was determined from empirical equations obtained from Ref. 1 as follows:

$$UA = \frac{1}{\frac{1}{U_o} + \frac{th}{K} + \frac{1}{U_i}} \cdot A$$

$$U_o = .11 \frac{k}{D_o} \left[\frac{D_o^3 \rho^2 C_p \beta g \Delta t}{\mu k} \right]^{1/3} \qquad \text{(air to tank wall)}$$

$k = .0135$ BTU/hr Ft^2 °F/ft	thermal conductivity of air
$D_o = 14.5$ in = 1.20833 ft	tank diameter
$\rho = .0764/3 = .025466$ lb/ft^3	density of air
$C_p = .243$ BTU/lb °F	specific heat of air
$\beta = 1/460$ 1/°R	Coefficient of volumetric expansion
$g = 4.17 \times 10^8$ ft/hr^2	gravitational constant
$\Delta t = 90$ °F	temp differential - air to tank
$\mu = .1476$ lb/ft. hr	viscosity of air

$\underline{U_o = .276 \text{ BTU/hr. ft}^2 \text{ °F}}$

$$U_i = 3 \times \frac{.6k}{l} \left[\frac{\rho^2 C_p \beta g \Delta t}{\mu k} \right]^{1/3} \qquad \text{(tank wall to } NH_3\text{)}$$

k = .29 BTU/hr.ft^2°F/ft	thermal conductivity of NH_3
l = 52"~4 ft	length of tank
ρ = 36.955 lb/ft^3	density of NH_3
C_p = 1.163 BTU/lb°F	specific heat of NH_3
β = 1/550 1/°R	coefficient of volumetric expansion
Δt = 90°F	temp differential - NH_3 to tank
μ = .242 lb/ft.hr	viscosity of NH_3

U_i = 201 BTU/hr ft^2°F

th/k =

th = .185 in	tank wall thickness
k = 460 BTU/hr ft^2 °F/in	thermal conductivity of carbon steel

th/k = .402

U = .2756 BTU/hr ft^2 °F

The six storage tanks are cylinders, 52 in long, 14.5 in O.D., .185 in wall thickness, flat on one end and a hemisphere on the other end.

$$A = 6 \times \left(\left(\frac{14.5}{12 \times 2}\right)^2 \times \pi + \left(\frac{14.5}{\pi}\right) \times \pi \times \frac{37.5}{12} + \frac{4\pi}{2}\left(\frac{14.5}{12 \times 2}\right)^2 \right)$$

$= 91.82$ ft^2

UA = 25.3 BTU/hr °R

At a Δt of 90°F this will yield a heat transfer rate of

$$\dot{Q} = UA\,\Delta t$$
$$= 2277 \text{ BTU/hr}$$

To be conservative, we used a maximum value of

$$\dot{Q} = 3000 \text{ BTU/hr}$$

Over the range of interest, the thermodynamic properties of NH_3 at saturation conditions are essentially functions of temperature. A simple computer program was written to perform an iterative solution for these interrelated properties, given initial conditions, NH_3 flowrate, and external heat transfer rate, and calculate NH_3 temperatures and pressures. Minimum temperatures and pressures obtained, at a flowrate of 300 lb/hr and varying external heat transfer rates are shown in the following table.

EXTERNAL HEAT TRANSFER RATE (BTU/HR)	AMMONIA	
	TEMPERATURE °F	PRESSURE PSIA
-3000	47.9	85.7
-2000	59.9	107.4
-1000	70.9	131.0
0	76.6	152.2
1000	85.7	168.4
2000	91.5	185.1
3000	97.0	202.2

CONCLUSIONS

As is evident from the table above, the NH_3 tank pressures remained above 45 psia in all cases. This indicates that the required flowrate should be available at all times.

REFERENCE

1. Heat Transfer, Dr. B. E. Lauer, The Oil and Gas Journal, Tulsa, Okla., 9/29/52, 10/6/52, 3/16/53.